Digital Design &
Computer Architecture

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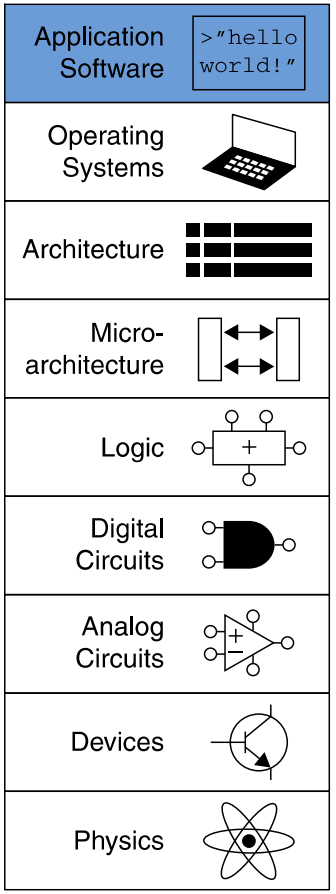
Appendix C:
C Programming

Appendix C :: Topics

- C Basics
- Functions
- Operators
- Control Flow
- Loops
- Arrays & Strings
- Structures
- Memory
- Pointers
- Dynamic Memory Allocation



Overview

- C programming language developed at Bell Labs around 1973
- Capable of controlling a computer to do nearly anything, including directly interacting with the hardware
- Suitable for generating high performance code
- Relatively easy to use
- Available from supercomputers to microcontrollers
- Closely related to other important languages including C++, C#, Objective C, Java, Arduino

C is Libertarian

- Lets you do just about anything
- Interacts directly with the hardware
- Does NOT protect you from your own stupidity
- Assumes YOU know the size of arrays and variables
- Unless sandboxed, can write ANYWHERE in memory

Example

```
// factorial.c
// David_Harris@hmc.edu 22 October 2019

int fact(int n) {
        if (n <= 1) return 1;
        else return n*fact(n-1);
}

void main(void) {
        int result;
        result = fact(4);
}
```

Steps to C Programming

- Write code
- Compile code
- Execute code
- Debug code

Appendix C: C Programming

C Basics

Comments

- Single-line comments begin with "//" and continue to the end of the line.

```
x += 2; //This is a single-line comment.
```

- Multi-line comments begin with "/*" end with "*/".

```
/* You can hide or disable a section of code such as this block
with a multi-line comment
      x = bob ? x : y;
      y -= 5;
*/
```

- Always start code with the file name, your name, email, and date. This gives you copyright ownership & helps the next programmer track you down.

Constants, Defines, or Macros

- Constants are named using the #define directive

  #define MAXGUESSES 5

  #define PI 3.14159
- The # indicates that this line in the program will be handled by the preprocessor.
- Before compilation, the preprocessor replaces each occurrence of the identifier MAXGUESSES in the program with 5.
- By convention, #define lines are located at the top of the file and identifiers are written in all capital letters.

Global and Local Variables

- Global variables are declared outside of any function
  - Accessible from all functions
  - Often lead to hard-to-debug code
  - Should be avoided, especially in large programs
- Local variables are declared inside a function
  - Only accessible in that function
  - Should be your preferred choice

Primitive Data Types

Type	Size (bits)	Minimum	Maximum
`char`	8	$-2^{-7} = -128$	$2^7 - 1 = 127$
`unsigned char`	8	0	$2^8 - 1 = 255$
`short`	16	$-2^{15} = -32{,}768$	$2^{15} - 1 = 32{,}767$
`unsigned short`	16	0	$2^{16} - 1 = 65{,}535$
`long`	32	$-2^{31} = -2{,}147{,}483{,}648$	$2^{31} - 1 = 2{,}147{,}483{,}647$
`unsigned long`	32	0	$2^{32} - 1 = 4{,}294{,}967{,}295$
`long long`	64	-2^{63}	$2^{63} - 1$
`unsigned long`	64	0	$2^{64} - 1$
`int`	machine-dependent		
`unsigned int`	machine-dependent		
`float`	32	$\pm 2^{-126}$	$\pm 2^{127}$
`double`	64	$\pm 2^{-1023}$	$\pm 2^{1022}$

Integer Sizes

- Integer sizes in C may vary with the machine
  - int may be 16 or 32 bits
  - long may be 32 or 64 bits
  - Best to use sized types if size truly matters
  - But their names are a bit cumbersome
  - #include <stdint.h>
- Signed: int16_t, int32_t, int64_t
- Unsigned: uint16_t, uint32_t, uint64_t

ASCII Table

ASCII TABLE

Decimal	Hexadecimal	Binary	Octal	Char
0	0	0	0	*[NULL]*
1	1	1	1	*[START OF HEADING]*
2	2	10	2	*[START OF TEXT]*
3	3	11	3	*[END OF TEXT]*
4	4	100	4	*[END OF TRANSMISSION]*
5	5	101	5	*[ENQUIRY]*
6	6	110	6	*[ACKNOWLEDGE]*
7	7	111	7	*[BELL]*
8	8	1000	10	*[BACKSPACE]*
9	9	1001	11	*[HORIZONTAL TAB]*
10	A	1010	12	*[LINE FEED]*
11	B	1011	13	*[VERTICAL TAB]*
12	C	1100	14	*[FORM FEED]*
13	D	1101	15	*[CARRIAGE RETURN]*
14	E	1110	16	*[SHIFT OUT]*
15	F	1111	17	*[SHIFT IN]*
16	10	10000	20	*[DATA LINK ESCAPE]*
17	11	10001	21	*[DEVICE CONTROL 1]*
18	12	10010	22	*[DEVICE CONTROL 2]*
19	13	10011	23	*[DEVICE CONTROL 3]*
20	14	10100	24	*[DEVICE CONTROL 4]*
21	15	10101	25	*[NEGATIVE ACKNOWLEDGE]*
22	16	10110	26	*[SYNCHRONOUS IDLE]*
23	17	10111	27	*[ENG OF TRANS. BLOCK]*
24	18	11000	30	*[CANCEL]*
25	19	11001	31	*[END OF MEDIUM]*
26	1A	11010	32	*[SUBSTITUTE]*
27	1B	11011	33	*[ESCAPE]*
28	1C	11100	34	*[FILE SEPARATOR]*
29	1D	11101	35	*[GROUP SEPARATOR]*
30	1E	11110	36	*[RECORD SEPARATOR]*
31	1F	11111	37	*[UNIT SEPARATOR]*
32	20	100000	40	*[SPACE]*
33	21	100001	41	!
34	22	100010	42	"
35	23	100011	43	#
36	24	100100	44	$
37	25	100101	45	%
38	26	100110	46	&
39	27	100111	47	'
40	28	101000	50	(
41	29	101001	51	)
42	2A	101010	52	*
43	2B	101011	53	+
44	2C	101100	54	,
45	2D	101101	55	-
46	2E	101110	56	.
47	2F	101111	57	/
48	30	110000	60	0
49	31	110001	61	1
50	32	110010	62	2
51	33	110011	63	3
52	34	110100	64	4
53	35	110101	65	5
54	36	110110	66	6
55	37	110111	67	7
56	38	111000	70	8
57	39	111001	71	9
58	3A	111010	72	:
59	3B	111011	73	;
60	3C	111100	74	<
61	3D	111101	75	=
62	3E	111110	76	>
63	3F	111111	77	?
64	40	1000000	100	@
65	41	1000001	101	A
66	42	1000010	102	B
67	43	1000011	103	C
68	44	1000100	104	D
69	45	1000101	105	E
70	46	1000110	106	F
71	47	1000111	107	G
72	48	1001000	110	H
73	49	1001001	111	I
74	4A	1001010	112	J
75	4B	1001011	113	K
76	4C	1001100	114	L
77	4D	1001101	115	M
78	4E	1001110	116	N
79	4F	1001111	117	O
80	50	1010000	120	P
81	51	1010001	121	Q
82	52	1010010	122	R
83	53	1010011	123	S
84	54	1010100	124	T
85	55	1010101	125	U
86	56	1010110	126	V
87	57	1010111	127	W
88	58	1011000	130	X
89	59	1011001	131	Y
90	5A	1011010	132	Z
91	5B	1011011	133	[
92	5C	1011100	134	\
93	5D	1011101	135	]
94	5E	1011110	136	^
95	5F	1011111	137	_
96	60	1100000	140	`
97	61	1100001	141	a
98	62	1100010	142	b
99	63	1100011	143	c
100	64	1100100	144	d
101	65	1100101	145	e
102	66	1100110	146	f
103	67	1100111	147	g
104	68	1101000	150	h
105	69	1101001	151	i
106	6A	1101010	152	j
107	6B	1101011	153	k
108	6C	1101100	154	l
109	6D	1101101	155	m
110	6E	1101110	156	n
111	6F	1101111	157	o
112	70	1110000	160	p
113	71	1110001	161	q
114	72	1110010	162	r
115	73	1110011	163	s
116	74	1110100	164	t
117	75	1110101	165	u
118	76	1110110	166	v
119	77	1110111	167	w
120	78	1111000	170	x
121	79	1111001	171	y
122	7A	1111010	172	z
123	7B	1111011	173	{
124	7C	1111100	174	|
125	7D	1111101	175	}
126	7E	1111110	176	~
127	7F	1111111	177	*[DEL]*

https://commons.wikimedia.org/wiki/File:ASCII-Table.svg

Appendix C: C Programming

Functions

Functions

- A function may take some inputs and may return at most one output
- The type of the inputs is declared in the function declaration
- Functions pass variables by *value* not *reference*
- Curly braces {} enclose the body of the function, which may contain zero or more statements
- The type of returned value is declared in the function declaration
- The return statement indicates the value that the function should return to its caller
- A function must be either declared BEFORE it is used or a function prototype declared BEFORE it is used

Function Example

```
// Return the sum of the three input variables

int sum3(int a, int b, int c) {
  int result = a + b + c;
  return result;
}
```

Function Prototypes

```
// sum3example.c
// David_Harris@hmc.edu 22 October 2019

////////////////////////////////
// Prototypes
////////////////////////////////
int sum3(int, int, int); // needed because sum3 is called before declared

////////////////////////////////
// main
////////////////////////////////

void main(void) {
  int answer;
  answer = sum3(6, 7, 8);
}

////////////////////////////////
// other functions
// prototype not needed if these were moved before main
////////////////////////////////

int sum3(int a, int b, int c) {
  int result = a + b + c;
  return result;
}
```

Prototypes are Sometimes Unavoidable

```
// Prototypes needed for f1 and/or f2 because they
// can't both be declared before each other

int f1(int);
int f2(int);

int f1(int n) {
  return f2(n-1) + 1;
}

int f2(int n) {
  return f1(n-1)*2;
}

void main(void) {
  int answer;
  answer = f1(5);
}
```

Includes

- The function prototypes for the standard libraries are included at the top of a file with the #include directive:

```
#include <stdio.h>
#include <math.h>
```

- Your own function prototypes (or anything else you want to include) is done with quotes instead of brackets for relative or absolute path:

  e.g., #include "other/myFuncs.h"

Operators

Boolean (True/False) in C

- A variable or expression is considered FALSE if its value is 0
- A variable is considered TRUE if it has any other value
  - 1, 42, and -1 are all TRUE for C
- Logical operators assign FALSE as 0 and TRUE as 1

Operators and Precedence

Category	Operator	Description	Example
Unary	++	post-increment	`a++; // a = a+1`
	--	post-decrement	`x--; // x = x–1`
	&	memory address of a variable	`x = &y; // x = the memory // address of y`
	~	bitwise NOT	`z = ~a;`
	!	Boolean NOT	`!x`
	–	negation	`y = -a;`
	++	pre-increment	`++a; // a = a+1`
	--	pre-decrement	`--x; // x = x–1`
	(type)	casts a variable to (type)	`x = (int)c; // cast c to an // int and assign it to x`
	sizeof()	size of a variable or type in bytes	`long int y; x = sizeof(y); // x = 4`

Operators Continued

Multiplicative	*	multiplication	`y = x * 12;`
	/	division	`z = 9 / 3; // z = 3`
	%	modulo	`z = 5 % 2; // z = 1`
Additive	+	addition	`y = a + 2;`
	–	subtraction	`y = a - 2;`
Bitwise Shift	<<	bitshift left	`z = 5 << 2; // z = 0b00010100`
	>>	bitshift right	`x = 9 >> 3; // x = 0b00000001`
Relational	==	equals	`y == 2`
	!=	not equals	`x != 7`
	<	less than	`y < 12`
	>	greater than	`val > max`
	<=	less than or equal	`z <= 2`
	>=	greater than or equal	`y >= 10`

Operators Continued

Table eC.3 Operators listed by decreasing precedence—Cont'd

Category	Operator	Description	Example
Bitwise	`&`	bitwise AND	`y = a & 15;`
	`^`	bitwise XOR	`y = 2 ^ 3;`
	`|`	bitwise OR	`y = a | b;`
Logical	`&&`	Boolean AND	`x && y`
	`||`	Boolean OR	`x || y`
Ternary	`? :`	ternary operator	`y = x ? a : b; // if x is TRUE, // y=a, else y=b`

Operators Continued

Assignment	=	assignment	`x = 22;`	
	+=	addition and assignment	`y += 3;`	`// y = y + 3`
	-=	subtraction and assignment	`z -= 10;`	`// z = z - 10`
	*=	multiplication and assignment	`x *= 4;`	`// x = x * 4`
	/=	division and assignment	`y /= 10;`	`// y = y / 10`
	%=	modulo and assignment	`x %= 4;`	`// x = x % 4`
	>>=	bitwise right-shift and assignment	`x >>= 5;`	`// x = x>>5`
	<<=	bitwise left-shift and assignment	`x <<= 2;`	`// x = x<<2`
	&=	bitwise AND and assignment	`y &= 15;`	`// y = y & 15`
	|=	bitwise OR and assignment	`x |= y;`	`// x = x | y`
	^=	bitwise XOR and assignment	`x ^= y;`	`// x = x ^ y`

Examples

```
int a = 42;
int b = 0x15;                  // hexadecimal; = 21 in decimal
char c = 0b00001010;           // binary; = 10 in decimal

char d = !c;                   // 0, because c was nonzero
char e = ~c;                   // 0b11110101 bitwise NOT
char f = e | c;                // 0b11111111 bitwise OR
char g = c << 2;               // 0b00101000 shift left by 2
int h = (a > b);               // 1 because a is greater than b
int i = (a > b)&&(c != e);     // 1 because both are TRUE
int j = (a > b) ? a : b;       // 42 because a > b
int k = sizeof(a);             // 4 on most computers
g &= c;                        // 0b00001000 bitwise AND
```

Appendix C: C Programming

Control Flow

Control Flow Statements

if

```
if (expression)
  statement;
```

if/else

```
if (expression)
  statement1;
else
  statement2;
```

switch/case

```
switch (variable) {
  case (expression1): statement1; break;
  case (expression2): statement2; break;
  case (expression3): statement3; break;
  default: statement4;
}
```

Don’t forget “break” or “default”

If example

```
if (n <= 1) return 1;
```

Compound Statements

- When a statement has more than one line, enclose it in {}

```
if (answer == 42) {
  ultimateQuestion = 1;
  hitchhikersGuide = 1;
}
```

If/else example

```
if (n <= 1) return 1;
else        return fact(n-1);
```

Switch/case example

```
switch (state) {
  case (0): if (ta) state = 0; else state = 1; break;
  case (1): state = 2; break;
  case (2): if (tb) state = 2; else state = 3; break;
  case (3): state = 0; break;
  default:  state = 0;
}
```

Appendix C: C Programming

Loops

Loops

while

```
while (condition)
  statement;
```

do/while

```
do {
  statement;
} while (condition);
```

for

```
for (initialization; condition; loop operation)
  statement;
```

While example

```
int fact(int n) {
  int result = 1;
  while (n > 1) {
    result = result * n; // or write result *= n;
    n = n - 1;           // or write n--
  }
  return result;
}

// Alternative while loop is shorter but less clear

int fact(int n) {
  int result = 1;
  while (n > 1) result *= n--;
  return result;
}
```

Do/while example

```
int fact(int n) {
  int result = 1;
  do {
    result *= n;
  } while (n-- > 1);
  return result;
}
```

- Do always executes the statement at least once.
- Longer and not preferred for this example

For example

```
int fact(int n) {
  int result = 1;
  int i;

  for (i=1; i <= n; i++)
    result *= i;
  return result;
}
```

- First do initialization (i = 1)
- Then check condition (i<=n)
  - If satisfied, do body (result *= i)
  - Then do loop operation (i++)
- Then repeat from checking condition

Appendix C: C Programming

Arrays & Strings

Data Types: Arrays

- Array contains multiple elements

```
float accel[3];
```

- The elements are numbered from 0 to N−1, where N is the length of the array
- Initialize your arrays.
  - An uninitialized array can contain anything
- Arrays can be multidimensional

```
#define NUMSTUDENTS 120
#define NUMLABS 11
int grades[NUMSTUDENTS][NUMLABS];
```

Array Example

```
#include <math.h>

double mag(double v[3]) {
  return sqrt(v[0]*v[0] + v[1]*v[1] + v[2]*v[2]);
}
```

Data Types: Strings

- A string is an array of characters
- Last entry is zero to indicate end (”NULL terminated”)

```
char name[20] = "BOB";
```

- Stored as:

name[0] = 66; // ASCII value for B

name[1] = 79; // ASCII value for O

name[2] = 66; // ASCII value for B

name[3] = 0; // NULL termination

other entries are junk, ignored

Examples: String Handling

```
#define MAXLEN 80

int strlen(char str[]) {
  int len=0;

  while (str[len] && len < MAXLEN) len++;
  return len;
}

void strcpy(char dest[], char src[]) {
  int i = 0;

  do {
    dest[i] = src[i];
  } while (src[i++] && i < MAXLEN);
}
```

Examples: Using Strings

```
#include <string.h>
#define MAXLEN 80

void main(void) {
  char name[80];
  int len;
  char c;

  strcpy(name, "BOB"); // copy BOB into name
  len = strlen(name);  // len = 3
  c = name[1];         // c = 'O' (79)
}
```

Appendix C: C Programming

Structures

Structures

- Store a collection of related information
- General format:

```
struct name {
  type1 element1;
  type2 element2;
  ...
};
```

Structures

```
struct contact {
  char name[30];
  int age;
  float height; // in meters
};

struct contact c1;
strcpy(c1.name, "Ben Bitdiddle”);
c1.age = 20;
c1.height = 1.82;
```

Typedef

- If you're using lots of the same structure, you can shorten your typing by using typedef.
- typedef *type name*;

```
typedef struct contact {
  char name[30];
  int age;
  float height; // in meters
} contact; // defines contact as shorthand for "struct contact"

contact c1; // now we can declare the variable as type contact
```

Structure Examples

```
typedef struct point {
  int x;
  int y;
} point;

point p1;
p1.x = 42; p1.y = 9;
```

```
typedef struct rect {
  point ll;
  point ur;
  int color;
} rect;

rect r1;
r1.color = 1;
r1.ll = p1;
r1.ur.x = r1.ll.x + width;
r1.ur.y = r1.ll.y + height;
```

Appendix C: C Programming

Memory

Memory

- Variables are stored in memory
- Each primitive data type has a size
  - char 1 byte
  - short at least 2 bytes
  - long at least 4 bytes, 8 on some 64-bit computers
  - int at least 2 bytes, 4 on most 32 & 64-bit computers
  - float 4 bytes
  - double 8 bytes
- Arrays & structs stored in multiple consecutive locations

Sizeof

- Sizeof operator returns size of a datatype

```
char c;
double d;
point p;
rect r;
int s1 = sizeof c;  // s1 = 1
int s2 = sizeof(d); // s2 = 8
int s3 = sizeof(p); // s3 = 4 + 4 = 8
int s4 = sizeof(r); // s4 = 8 + 8 + 4 = 20
```

Memory Example: Array

C Code Example eC.21 ARRAY INITIALIZATION AT DECLARATION USING { }

```
long scores[3]={93, 81, 97}; // scores[0]=93; scores[1]=81; scores[2]=97;
```

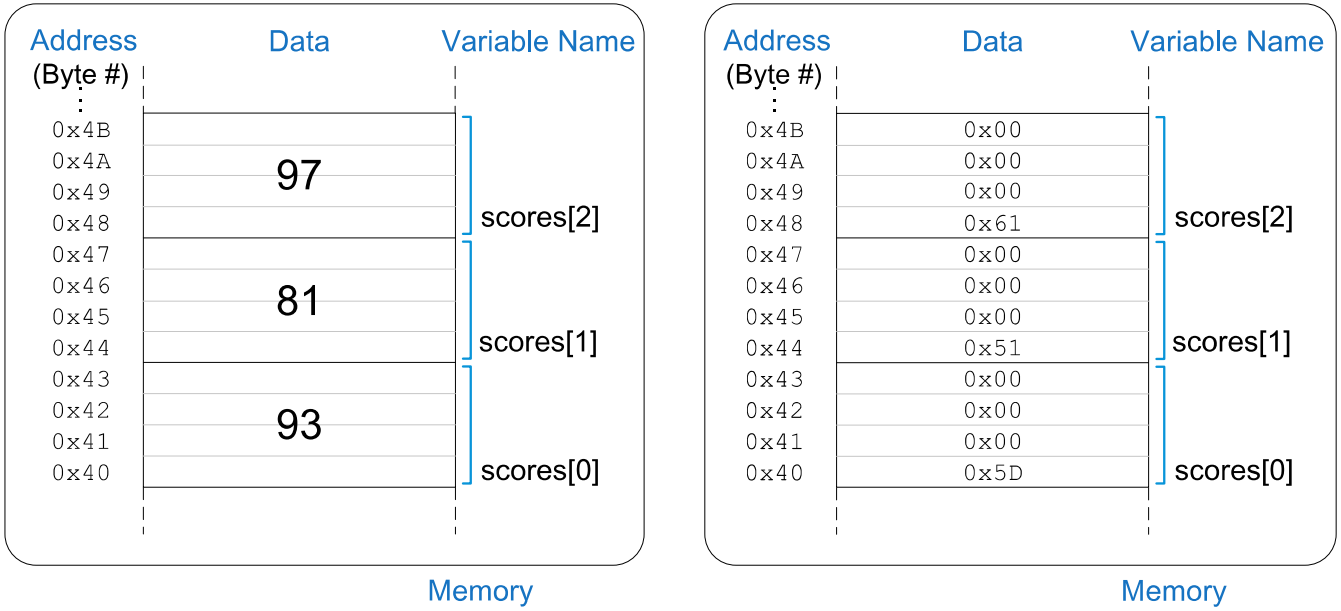
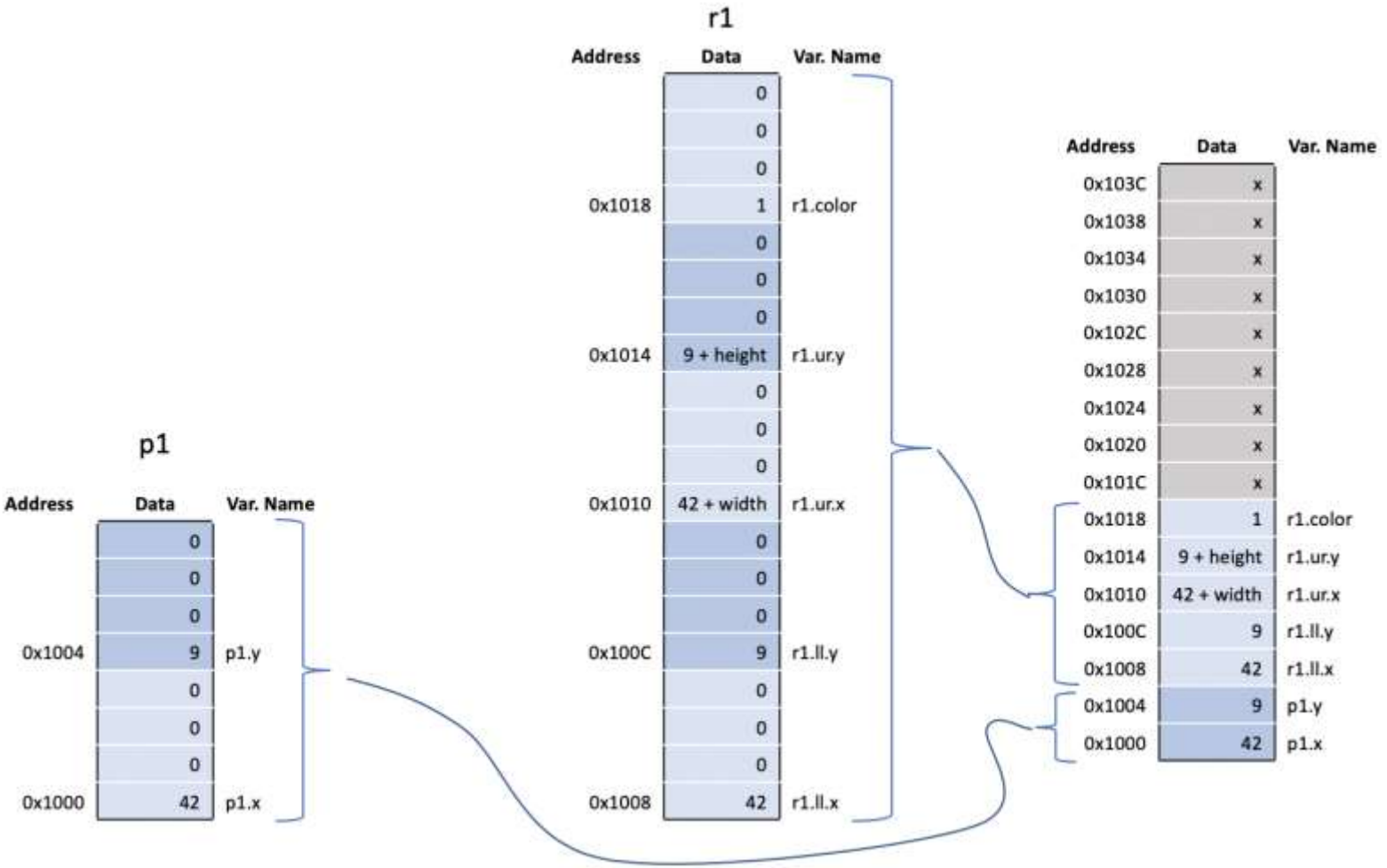


Figure eC.4 `scores` **array stored in memory**

Memory Example: Structure



Appendix C: C Programming

Pointers

Pointers

- A pointer is an address in memory
- Pointer variables are declared with * and a data type to which the pointer points

```
int salary1, salary2;
int *ptr;    // a pointer to an integer
```

- & returns address of a variable

```
salary1 = 98500;   // suppose this is at address 100 in memory
ptr = &salary1;    // ptr contains 100 (the address of salary1)
```

- * dereferences a pointer (finds value it points to)

```
salary2 = *ptr + 1000; // salary2 gets 99500
```

Arrays and Pointers

- An array in C is viewed as the address of the zeroth element
- Equivalent to a pointer to the beginning of the array

Pointer Example

Now add:

```
int ary[4]; // suppose at addresses 0x101C, 0x1020, 0x1024, 0x1028
int a = 37, b;
int *ptr;
int i;
```

Address	Data	Var. Name
0x103C	x	
0x1038	x	
0x1034	x	
0x1030	x	
0x102C	x	
0x1028	x	
0x1024	x	
0x1020	x	
0x101C	x	
0x1018	1	r1.color
0x1014	9 + height	r1.ur.y
0x1010	42 + width	r1.ur.x
0x100C	9	r1.ll.y
0x1008	42	r1.ll.x
0x1004	9	p1.y
0x1000	42	p1.x

Pointer Example

Now add:

```
int ary[4]; // suppose at addresses 0x101C, 0x1020, 0x1024, 0x1028
int a = 37, b;
int *ptr;
int i;
```

Address	Data	Var. Name
0x103C	x	
0x1038	x	
0x1034	x	
0x1030	x	
0x102C	x	
0x1028	x	ary[3]
0x1024	x	ary[2]
0x1020	x	ary[1]
0x101C	x	ary[0]
0x1018	1	r1.color
0x1014	9 + height	r1.ur.y
0x1010	42 + width	r1.ur.x
0x100C	9	r1.ll.y
0x1008	42	r1.ll.x
0x1004	9	p1.y
0x1000	42	p1.x

Pointer Example

Now add:

```
int ary[4]; // suppose at addresses 0x101C, 0x1020, 0x1024, 0x1028
int a = 37, b; // suppose at addresses 0x102C, 0x1030
int *ptr;
int i;
```

Address	Data	Var. Name
0x103C	x	
0x1038	x	
0x1034	x	
0x1030	x	b
0x102C	37	a
0x1028	x	ary[3]
0x1024	x	ary[2]
0x1020	x	ary[1]
0x101C	x	ary[0]
0x1018	1	r1.color
0x1014	9 + height	r1.ur.y
0x1010	42 + width	r1.ur.x
0x100C	9	r1.ll.y
0x1008	42	r1.ll.x
0x1004	9	p1.y
0x1000	42	p1.x

Pointer Example

Now add:

```
int ary[4]; // suppose at addresses 0x101C, 0x1020, 0x1024, 0x1028
int a = 37, b; // suppose at addresses 0x102C, 0x1030
int *ptr;  // suppose ptr is at address 0x1034, initially undefined
int i;
```

Address	Data	Var. Name
0x103C	x	
0x1038	x	
0x1034	x	ptr
0x1030	x	b
0x102C	37	a
0x1028	x	ary[3]
0x1024	x	ary[2]
0x1020	x	ary[1]
0x101C	x	ary[0]
0x1018	1	r1.color
0x1014	9 + height	r1.ur.y
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Address	Data	Var. Name
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Pointer Example

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int a = 37, b; // suppose at addresses 0x102C, 0x1030
int *ptr;  // suppose ptr is at address 0x1034, initially undefined
int i;

for (i=0; i<3; i++) ary[i] = i*i;
ptr = &a;
b = *ptr;
*ptr = 3;
ptr = ary;
ptr[1] = b;
*(ptr+2) = 7;
ary[4] = 1;
*(ptr+5) = 2;
```

Address	Data	Var. Name
0x103C	x	
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0x1034	x	ptr
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int ary[4]; // suppose at addresses 0x101C, 0x1020, 0x1024, 0x1028
int a = 37, b; // suppose at addresses 0x102C, 0x1030
int *ptr;  // suppose ptr is at address 0x1034, initially undefined
int i;

for (i=0; i<3; i++) ary[i] = i*i; // Note: ary[3] not changed
ptr = &a;
b = *ptr;
*ptr = 3;
ptr = ary;
ptr[1] = b;
*(ptr+2) = 7;
ary[4] = 1;
*(ptr+5) = 2;
```

Address	Data	Var. Name
0x103C	x	
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for (i=0; i<3; i++) ary[i] = i*i;
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b = *ptr;
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int *ptr;  // suppose ptr is at address 0x1034, initially undefined
int i;

for (i=0; i<3; i++) ary[i] = i*i;
ptr = &a;     // ptr = 0x102C
b = *ptr;     // dereference pointer, b = 37
*ptr = 3;
ptr = ary;
ptr[1] = b;
*(ptr+2) = 7;
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Address	Data	Var. Name
0x103C	x	
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b = *ptr;     // dereference pointer, b = 37
*ptr = 3;     // a = 3
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for (i=0; i<3; i++) ary[i] = i*i;
ptr = &a;     // ptr = 0x102C
b = *ptr;     // dereference pointer, b = 37
*ptr = 3;     // a = 3
ptr = ary;    // ptr = 0x101C
ptr[1] = b;   // ary[1] = 37
*(ptr+2) = 7;
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b = *ptr;     // dereference pointer, b = 37
*ptr = 3;     // a = 3
ptr = ary;    // ptr = 0x101C
ptr[1] = b;   // ary[1] = 37
*(ptr+2) = 7; // ary[2] = 7, note offset is in int sizes, not bytes
ary[4] = 1;
*(ptr+5) = 2;
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Address	Data	Var. Name
0x103C	x	
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int *ptr;  // suppose ptr is at address 0x1034, initially undefined
int i;

for (i=0; i<3; i++) ary[i] = i*i;
ptr = &a;     // ptr = 0x102C
b = *ptr;     // dereference pointer, b = 37
*ptr = 3;     // a = 3
ptr = ary;    // ptr = 0x101C
ptr[1] = b;   // ary[1] = 37
*(ptr+2) = 7; // ary[2] = 7, note offset is in int sizes, not bytes
ary[4] = 1;   // a = 1, BAD: trash variable past end of array
*(ptr+5) = 2;
```

Address	Data	Var. Name
0x103C	x	
0x1038	3	i
0x1034	0x101C	ptr
0x1030	37	b
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0x1028	x	ary[3]
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int *ptr;  // suppose ptr is at address 0x1034, initially undefined
int i;

for (i=0; i<3; i++) ary[i] = i*i;
ptr = &a;     // ptr = 0x102C
b = *ptr;     // dereference pointer, b = 37
*ptr = 3;     // a = 3
ptr = ary;    // ptr = 0x101C
ptr[1] = b;   // ary[1] = 37
*(ptr+2) = 7; // ary[2] = 7, note offset is in int sizes, not bytes
ary[4] = 1;   // a = 1, BAD: trash variable past end of array
*(ptr+5) = 2; // b = 2, BAD: trash variable past end of array
```

Address	Data	Var. Name
0x103C	x	
0x1038	3	i
0x1034	0x101C	ptr
0x1030	2	b
0x102C	1	a
0x1028	x	ary[3]
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0x1008	42	r1.ll.x
0x1004	9	p1.y
0x1000	42	p1.x

Another Example

C Code

```
#include <stdio.h>

int main (void)
{
  char age = 30;
  char *p;
  p = &age;
  printf("age = %d\n", age);
  printf("p = %p\n", p);
  printf("*p = %d\n", *p);
  printf("sizeof(age) = %ld\n", sizeof(age));
  printf("sizeof(p) = %ld\n", sizeof(p));
  *p = 40;
  printf("*p = %d\n", *p);
  printf("age = %d\n", age);
  return 0;
}
```

Program Output

```
      age = 30
        p = 0x7ffee31
       *p = 30
sizeof(age) = 1
 sizeof(p) = 8
       *p = 40
      age = 40
```

Another Example

C Code

```
#include <stdio.h>

int main (void)
{
  char age = 30;
  char *p;
  p = &age;
  printf("age = %d\n", age);
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  printf("*p = %d\n", *p);
  printf("sizeof(age) = %ld\n", sizeof(age));
  printf("sizeof(p) = %ld\n", sizeof(p));
  *p = 40;
  printf("*p = %d\n", *p);
  printf("age = %d\n", age);
  return 0;
}
```

Program Output

```
      age = 30
        p = 0x7ffee311e82b
       *p = 30
sizeof(age) = 1
 sizeof(p) = 8
       *p = 40
      age = 40
```

Pointers and Structures

```
rect *rptr; // Let rptr know it's pointing to a rect
rptr = &r1; // Have rptr point at r1

(*rptr).color = 3;  // Change r1.color to 3
rptr->color = 4;    // Change r1.color to 4

// Use dot "." when you are using the structure name.
// Arrow "->" (member access operator) is preferred when you are using the
pointer.
```

Address	Data	Var. Name
0x103C	x	
0x1038	3	i
0x1034	0x101C	ptr
0x1030	2	b
0x102C	1	a
0x1028	x	ary[3]
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0x1004	9	p1.y
0x1000	42	p1.x

Appendix C: C Programming

Memory

Odds & Ends

Passing Structures to Functions

Complex data structures and arrays are normally passed to C programs by address rather than copied; it's more efficient.

```
void createRect(int xl, int yl, int width, int height, int color, rect *r) {
  r->ll.x = x1; r->ll.y = yl;
  r->ur.x = xl + width; r->ur.y = yl + height;
  r->color = color;
}

int main(void) {
  rect r1;
  createRect(3, 5, 10, 20, 1, &r1);
}
```

Multidimensional Arrays

- Stored in consecutive addresses
  - last dimension first

```
double field[2][3][3];
```

Address0	Entry
0x1068	field[1][2][2]
0x1060	field[1][2][1]
0x1068	field[1][2][0]
0x1060	field[1][1][2]
0x1068	field[1][1][1]
0x1060	field[1][1][0]
0x1068	field[1][0][2]
0x1060	field[1][0][1]
0x1068	field[1][0][0]
0x1060	field[0][2][2]
0x1068	field[0][2][1]
0x1060	field[0][2][0]
0x1068	field[0][1][2]
0x1060	field[0][1][1]
0x1058	field[0][1][0]
0x1050	field[0][0][2]
0x1048	field[0][0][1]
0x1040	field[0][0][0]

Complex Structures in Memory

```
typedef struct foo {
  double d[4][5];
  unsigned short s[16];
} foo;

foo z[10];
int s5 = sizeof(z[0]);
// 8*4*5 + 2*16 = 192 = 0xC0
int s5 = sizeof(z);
// 10*192 = 1920 = 0x780
```

Address	Entry
0x277E	z[9].s[15]
..	…
0x217E	z[1][s[15]
..	…
0x20C0	z[1].d[0][0]
0x20BE	z[0].s[15]
…	…
0x20A2	z[0].s[1]
0x20A0	z[0].s[0]
0x2098	z[0].d[3][4]
…	…
0x2008	z[0].d[0][1]
0x2000	z[0].d[0][0]

Appendix C: C Programming

Dynamic Memory Allocation

Memory Allocation

- malloc returns a pointer to allocated memory of a certain number of bytes.
- free frees this memory.
- These functions are declared in stdlib

- int *ary = (int*)malloc(10*sizeof(int));

Example: Variable Sized Arrays

- In standard C, multidimensional array sizes must be declared at compile time.
- Treat variable-sized M row x N column array as 1-dimensional array of M x N entries

Variable Dimension Matrix Example

```
#include <stdlib.h> // for malloc

double* newMatrix(int m, int n) {
  double *mat;

  mat = (double*)malloc(m*n*sizeof(double));
  return mat;
}

double* newIdentityMatrix(int n) {
  double *mat = newMatrix(n, n);
  int i, j;

  for (i=0; i<n; i++)
    for (j=0; j<n; j++)
      mat[j+i*n] = (i==j);
  return mat;
}
```

Variable Dimension Matrix Example

```
void scaleMatrix(double *mat, double *scaled, int m, int n, double c) {
  int i, j;

  for (i=0; i<m; i++)
    for (j=0; j<n; j++)
      scaled[j+i*n] = mat[j+i*n]*c;
}

int main(void) {
  double *m1, *m2;

  m1 = newIdentityMatrix(3);
  m2 = newMatrix(3, 3);
  scaleMatrix(m1, m2, 3, 3, 10);
  free(m1);
}
```

About these Notes

Digital Design and Computer Architecture Lecture Notes